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RESEARCHES

ON

ASTRONOMICAL SPECTRUM-PHOTOGRAPHY.

BY THE LATE

PROFESSOR HENRY DRAPER, M.D., LL.D.

Extracts from the Original Note Books,

WITH AN INTRODUCTION AND DESCRIPTION OF THE APPARATUS,

BY PROFESSOR C. A. YOUNG;

AND MEASUREMENTS AND DISCUSSION OF THE PLATES,

BY PROFESSOR E. C. PICKERING.

ALSO, REPRINTS OF DIFFERENT PAPERS UPON THE SUBJECT, AS ORIGINALLY
PUBLISHED BY DR. DRAPER.

CAMBRIDGE:
JOHN WILSON AND SON.
University Press.
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a Browning nine-prism direct-vision spectroscope (without slit) placed inside the focus of the 28-inch mirror, the sensitive plate being at the focus.

The 12-inch refractor was received at this time, and a good deal of photographic work was done with it to determine its actinic focus and other constants, but no photographs of stellar spectra were made with it this season. Its best actinic focus was found to be $\frac{62}{100}$ inch outside of the focus for G.

In July, 1876, several photographs of the spectrum of Vega were taken with an apparatus which Dr. Draper called the "spectrograph." It consisted of a box about three feet long, which screwed into the tailpiece of the reflector in place of the eyepiece. It consisted of the following parts: first, a slit; close behind this the brass tube of a Browning direct-vision spectroscope containing either 3, 6, or 9 prisms (variable at pleasure); next to this, and 14 inches from the slit, a 7-inch Voigtlander portrait-lens and camera. The results were not materially different from those obtained by the earlier methods, and the apparatus was so awkward that it was soon abandoned. At this time was introduced the plan of setting the slit in the direction of the right-ascensional motion, so that any slight irregularities of the driving-clock would only widen the spectrum a little, instead of removing the star's image from the slit. The use of a cylindrical lens to broaden the spectrum was not found to be of any particular advantage.

During September and early in October, 1876, experiments were tried by putting the Browning direct-vision prism, without slit or lens, inside the focus of the 12-inch refractor. A cylindrical lens of 14-inch focus could be placed either between the prism and the object-glass, or between the prism and the sensitive plate. The difficulty produced by the fact that the focus of the object-glass varies for different rays, was partly overcome by tilting the sensitive plate.

On October 9 the Huggins star-spectroscope seems first to have been brought into use, one prism only being employed. It was attached to the refractor, and at first used with wide open slit. It was found difficult but very important to adjust the collimator accurately in line with the optical axis of the large telescope.

On October 12 another stellar spectroscope was arranged, consisting, first, of a slit with an open space between it and the end of the telescope, so that one could see whether the star remained centred on the slit; then the nine-prism Browning direct-vision combination; then two opera-glass lenses, and behind this the plate-holder. This was attached to the reflector, and several stellar spectra were photographed with it; but they turned out very faint, and the removal of the slit did not make them any brighter.

October 18 and 19, 1876. Experiments were made upon the spectrum of Venus, both with the reflector and refractor, — the former giving much the stronger pictures. The plates show the lines very well, especially those between G and H. At this time an eyepiece was added for the purpose of watching the lower end of the spectrum, and so maintaining the adjustments.

October 25, 1876. Six photographs of the spectrum of Venus were made, which came out very satisfactorily. Experiments were made, giving data for determining the best width of slit.

October 27, 1876. Some photographs of the spectrum of Vega were made with the same apparatus, but results were not very satisfactory. The air was misty.

October 29, 1876. In the afternoon the same stellar spectroscope was attached to the 12-inch refractor, the aperture of which was reduced to $1\frac{1}{2}$ inches. The slit was closed so that *b* appeared distinctly triple, in the spectrum of the sun, and a series of photographs was made with exposures of 4 minutes, 1 minute, 5 seconds, and 1 second, respectively. The last proved just about the proper exposure, and indicates that the necessary exposure for Venus is 196 times that for the Sun.

During 1877 Dr. Draper was occupied mainly with work connected with his research upon the existence of oxygen in the Sun. In 1878 the season was occupied with the Transit of Mercury in May, and with the Solar Eclipse on July 29th; so that during these two years nothing was done with stellar spectra.

While in England, in June, 1879, he obtained some of Wratten and Wainwright's dry plates, and on his return resumed his stellar work with them. As the 28-inch mirror had not been resilvered since the removal of the film at the time of the Transit of Mercury, he used the 12-inch refractor for all his experiments, in connection with the Huggins star spectroscope, with *two* prisms, instead of only one, as in 1876. In October, he read before the National Academy of Sciences a paper upon the subject, which was published in the American Journal of Science for December, 1879.

The plates made by the collodion process up to and including 1876 were, of course, of no value for measurement, and have all been lost or destroyed, except about half a dozen "strippings" of the earliest ones, which still remain gummed into the note-books. For this reason it has seemed desirable to present the note-book data respecting them in the way which has been adopted.

In the list which follows, of the plates existing in the possession of Mrs. Draper, the remarks against each plate give all necessary details. The photographs were all taken with the Huggins star spectroscope with its two prisms, attached sometimes to the reflector, sometimes to the refractor, as indicated.

The first column of the table gives a current reference number; the second, the date; the third, the name of the object; the fourth, the local mean time of beginning of the exposure, when the note-books furnish it; the fifth, the duration of the exposure; the sixth, the width of the slit in thousandths of an inch; and the seventh, the aperture of the instrument used. Remarks follow quoted from the note-book. An asterisk denotes that the plate was one of those measured by Professor Pickering.

TABLE I.

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
1	1879. Aug. 6	α Lyræ		45m.	.006	12-in.	The spectrum is about ½ inch long from G to H. Put a finger in front of the slit so as to be able to shut off either the upper or lower part of it, and thus take a spectrum of a star with the moon or a planet juxtaposed upon the same plate for a reference spectrum.
2	Aug. 9	Sun		5s.			With the stellar spectroscope and a beam of sunlight from a heliostat, took some photographs of the sun's spectrum. Although the sun was somewhat obscured by clouds, 5 s. was too long an exposure, and the picture was burned out below H. The exposure of 30 s. to daylight answered better, and showed that these photographs extend nearly to F, instead of ending at G. On comparing these with the photograph of the spectrum of α Lyræ of August 6, it was found to extend above N (3580), and looks as if the great solar groups about L (3815) were represented in α Lyræ by bands.
3	Aug. 9	Daylight		30s.			
4	Aug. 11	Jupiter and α Lyræ		48m. 27m.	.007 .007	12-in. 12-in.	The evening was quite misty, — too much so to photograph the spectrum of α Bootis.
5	Aug. 12	α Lyræ and Jupiter	8h. 30m. to 12h.	40m. 30m.	.007 .007	12-in.	The evening was not clear, the sky being misty or covered by heavy clouds, which formed and dissolved away at intervals. The length of exposure specified is therefore uncertain, being the estimated clear periods during 3½ hours the plate was in the spectroscope. The mist cut off the more refrangible part of the spectrum. The two spectra shifted past each other a little in the photograph, but the adjacent coincidences are plain. To try to prevent, on another occasion, the spectra moving past each other when the telescope is changed from one star to another, as in the preceding photograph, the spectroscope was fastened to a piece of board.
6	Aug. 19	α Bootis		45m.		12-in.	Faint picture.

TABLE I. — *Continued.*

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
	1879.						
7	Aug. 19	*α* Lyræ and		47m.	.010	12-in.	Had to reverse the telescope for the exposure of *α* Lyræ, and, not having adjusted the finger well on the slit, the two spectra overlapped too much.
		Jupiter		47m.	.010	12-in.	
8	Sept. 15	Jupiter and		45m.	.011	12-in.	In this photograph the telescope was focused for the G rays on the slit.
		α Lyræ		43m.	.011	12-in.	
9	Sept. 17	Jupiter		30m.	.015	12-in.	In this picture the H rays were focused on the slit, but as the spectra did not extend as far into the violet as those taken before, the focus of the 12-inch telescope was changed to bring the G rays in focus on the slit. Took another photograph. In this both spectra were stronger, but *α* Lyræ did not extend to H.
		α Lyræ		49m.	.015	12-in.	
10	Sept. 17	Jupiter		45m.	.015	12-in.	
		α Lyræ		45m.	.015	12-in.	
11	Sept. 22	*α* Lyræ		49m.	.015	12-in.	The atmosphere was misty, and the moon looked very yellow. The spectrum of *α* Lyræ is very faint, and extends only from F to G.
		Jupiter		50m.	.015	12-in.	
12	Sept. 24	*α* Lyræ		54m.	.015	12-in.	The night was quite clear, but neither spectrum extended above H. G was still focused on the slit.
		Jupiter		30m.	.015	12-in.	
13	Sept. 24	Mars	11h. 30m. to	55m.	.015	12-in.	Mars and *α* Aurigæ were at about the same altitude. The two spectra are very much alike.
		α Aurigæ	13h. 15m.	48m.	.015	12-in.	
14	Sept. 25	*α* Lyræ		103m.	.015	12-in.	The night was clear. Gave *α* Lyræ two runs of the clock to try to get its spectrum above H. The moon's spectrum extends a long distance above H, but the spectrum of *α* Lyræ only to *h*. The moon was over-exposed.
		Moon		30m.	.015	12-in.	
15	Sept. 26	*α* Lyræ		45m.	.015	12-in.	The night was quite clear. The moon's spectrum is very strong, but there is no picture of *α* Lyræ. In this photograph, used a new gelatine plate, thinking the old one might have deteriorated, but found it of no advantage. When a star is adjusted on the slit so that the green end of the spectrum is the brightest, the violet loses brightness somewhat, and *vice versa*. Examined the spectroscope with sunlight and readjusted it, so as to be sure the violet end of the spectrum was not cut off by the prisms or lenses.
		Moon		10m.	.015	12-in.	
16	Sept. 27	*α* Lyræ		47m.	.015	12-in.	This evening went to the Observatory early enough to photograph the spectrum of *α* Lyræ, when the star was only a little past the meridian. Readjusting the spectroscope improved it. The spectra are strong, and extend above H. The G rays were focused on the slit.
		Moon		5m.	.015	12-in.	
17	Sept. 27	Jupiter	9h. 55m. to	50m.	.005	12-in.	Jupiter in this photograph was about 45° high, and the Moon about 50°. The exposure was made upon the meridian. During the latter part of the moon's exposure, the lens dewed over, therefore one could not judge of the relative brightness of the two. H rays were focused on the slit.
		Moon	10h. 55m.	10m.	.005	12-in.	
18	Sept. 27	Moon	11h. 21m. to	10m.	.005	12-in.	Got no impression of Mars, for the lens dewed over at the end of 25 m., and the sky clouded.
		Mars	12h.	25m.	.005	12-in.	
19	Oct. 4	*α* Lyræ	8h. 5m. to	45m.	.010	12-in.	A good picture.
		Jupiter	9h. 20m.	25m.	.010	12-in.	
20	Oct. 4	Jupiter	10h. 25m.	25m.	.010	12-in.	H rays focused on the slit. Spectrum of *α* Aurigæ was faint.
		α Aurigæ	11h. 48m.	50m.	.010	12-in.	

TABLE I. — *Continued.*

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
*21	1879–80. Oct. 4	α Aurigæ	12h. to 13h.	54m.	.010	12-in.	G rays focused on the slit.
		Moon		5m.	.010	12-in.	A good picture.
							During the winter of '79 and '80 a new worm wheel was made by Alvan Clark & Sons for the driving-clock, to replace the old one, which was found to be slightly eccentric. Dr. Draper moved to the country in June, 1880, and occupied a few days in getting it into place. It answered extremely well, and the clock was now sensibly perfect.
22	1880. June 9	α Bootis	9h. 27m. to 10h. 16m.	49m.	.010	12-in.	G rays were focused on the slit. The night was clear, but the picture is faint.
*23	June 13	α Bootis	9h. 20m. to 9h. 50m.	30m.	.015	12-in.	At the end of 30 m. the exposure was stopped by clouds. The night was so windy that the dome was blown around, and the force of the wind overcame the strength of the declination clamp, so that the telescope moved in declination, and made two impressions of the spectrum on the plate. Notwithstanding this, it is a good picture, extending from above H_2 to below F, showing a large number of lines, and a bright band on the more refrangible side of H. The G rays were focused on the slit.
*24	June 16	α Bootis	8h. 35m. to 9h. 30m.	50m.	.015	12-in.	Moon over-exposed, and α Bootis faint. The night was damp and not clear;
		Moon		3m.	.015	12-in.	bluish fog.
							At this time Dr. Draper exchanged the 12-inch for the 11-inch with photographic corrector referred to above. The new instrument was received July 9th, but was not fully ready for work until near the end of the month. The 28-inch reflector had been resilvered in the mean time, so that the spectroscope could be used either with it or with the refractor.
25	July 28	α Scorpii				11-in.	Sky clouded so there was no impression on the plate.
*26	July 29	α Lyræ	9h. to 9h. 25m.	25m.	.010	28-in.	Only about fifteen minutes of this exposure were clear, but it is a strong picture. The clouds cleared away, and the night became remarkably clear.
27	July 29	α Aquilæ		43m.	.010	28-in.	Fine picture.
28	July 29	α Aquilæ		38½m. 4¾m.	.010 .010	11-in. 11-in.	At the end of 38½ m., the star having moved to the west of the meridian, a slip in declination took place, owing to taking up the slack. This changed the position of the star on the plate, and made a second impression of 4¾ m.
29	July 30	α Scorpii	8h. 51m. to 10h. 10m.	45¾m.	.010	11-in.	Atmosphere was hazy, and the first 16 m. of the exposure α Scorpii was very
		α Aquilæ		30m.	.010	11-in.	faint on account of clouds. It had a good exposure of 30 m. After 9 o'clock the night was clear. α Scorpii's spectrum was faint, α Aquilæ's very strong.
*30	July 30	α Lyræ		7m. 28¾m.	.010 .010	11-in.	Before making this exposure on α Lyræ, moved the slit of the spectroscope outside the focus of the telescope 448 divisions of the micrometer, so as to widen the spectrum. After an exposure of 7 m. shifted the star on the plate, and then gave it the remaining time, 28¾ m., but the two pictures are nearly superposed.

TABLE I. — *Continued.*

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
31	1880. July 30	α Lyræ		4m. 30m.	.010 .010	11-in. 11-in.	Before this exposure, moved the slit of the spectroscope 394 divisions more outside the focus. The star was shifted on the plate after 4 m., making the second exposure of 30 m.
*32	July 31	α Bootis	8h. 49m. to 9h. 19m.	4½m. 25m.	.010	28-in.	The telescope slipped at the end of 4½ minutes, making two exposures on the plate. It was remarkably clear for a summer's night.
33	July 31	α Aquilæ		30m. 10m. 5m.	.010	28-in.	There are three exposures, the plate having been moved sideways at the end of 30 m., then again after 10 m., giving it a third exposure of 5 m. This picture required short development.
*34	July 31	α Lyræ		6m. 20m. 5m.	.010 .010 .010	28-in.	For this photograph, moved the spectroscope slit outside the focus to widen the spectrum. Made three exposures on the plate. The wind was so strong it moved the telescope in declination, and made it difficult to keep the star on the slit. This picture required short development.
*35	July 31	Jupiter		20m. 30m.	.010 .005	28-in.	At the end of 20 m. closed the slit to .005, and moved the star on the plate for the second exposure.
36	Aug. 1	α Scorpii		20m. 17m.	.010	28-in.	At the end of 20 m. the star slipped off the plate. Reset it, and exposed again for 17 m. During the first exposure the star was part of the time very faint. In the spectrum of α Scorpii there is a strong band in the orange.
37	Aug. 6	Jupiter	14h. 35m. 15h. 5m.	30m.	.006	11-in.	In the early part of the night took several photographs of Jupiter, showing the red spot. In taking this picture of the spectrum, placed the slit of the spectroscope near the preceding limb where the red spot was seen, but it had nearly disappeared.
38	Aug. 7	α Aquilæ		30m.	.006	11-in.	
*39	Aug. 9	α Scorpii	8h. 46m. to 9h. 26½m.	45½m.	.020	28-in.	Faint picture.
40	Aug. 9	α Aquilæ		10m. 15m. 12½m.	.020 .020 .020	28-in.	Star moved off the slit, and was reset between the exposures. The atmosphere was hazy.
*41	Aug. 12	α Aquilæ	9h. 47m. to 11h.	24m. 5m. 44m.	.010 .010 .005	28-in.	Night quite clear. At end of 24 m. star moved off the slit; reset it, and exposed again for 5 m. Moved the star again, closed the slit to .005, and made third exposure of 44 m.
*42	Aug. 12	α Aquilæ α Aquilæ Jupiter		18m. 10m. 12m.	.010 .010 .010	28-in. 28-in. 28-in.	α Aquilæ moved off the slit at 18 m., and was reset. 12 m. was not enough exposure for Jupiter; 15 or 20 would have been better.
*43	Aug. 12	α Aurigæ Jupiter	13h. 55m. to 14h. 47m.	30m. 20m.	.010 .010	28-in.	The image of the star was not quite focused on the slit.
44	Aug. 13	α Aquilæ		30m.	.010	28-in.	There was white mist in the sky.
	Aug. 13	α Lyræ		10m. 10m. 10m.	.003	28-in.	Reset the star between each of the three exposures.
*45	Aug. 15	α Lyræ		46m.	.002	28.in.	α Lyræ was not focused on the slit.
*46	Aug. 15	α Lyræ		44m.	.001	28-in.	Focused α Lyræ on the slit.
47	Aug. 16	α Scorpii Moon		42m. 3m.	.010 .010	28-in.	There was blue haze in the atmosphere. The finger on the slit was moved between the exposures of α Scorpii and the Moon, but was not well adjusted, so the two spectra are superposed.

TABLE I. — *Continued.*

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
*48	1880–81. Aug. 17	α Scorpii	8h. 12m. to 9h. 2m.	50m.	.010	28-in.	There was blue fog in the sky.
49	Aug. 17	α Aquilæ		49m.	.003	28-in.	The star slipped in declination at the end of 20 m., and again at 30 m., but was brought in position in a couple of minutes by the slow motion. The evening continued foggy.
50	Aug. 20	α Aquilæ		48m.	.001	28-in.	The plate was stained black by the moonlight in the room.
51	Aug. 22	α Aquilæ		48m.	.001	28-in.	The sky was hazy, but the picture is beautifully sharp, and shows the fine lines of this spectrum very distinctly.
52	Aug. 22	α Aquilæ Moon		49m. 5m.	.001 .001	28-in.	The moon's spectrum is faint, and α Aquilæ is not quite so sharp as in the preceding photograph.
53	Aug. 22	α Lyræ		48m.	.001	28-in.	This photograph was taken without any change being made in the apparatus, to see if, in the spectrum of α Lyræ, there was any trace of the system of fine lines which are characteristic of the spectrum of α Aquilæ, but no evidence of them was found. With the McLean spectroscopic eye-piece α Lyræ shows a line near D which may be D_3.
54	Aug. 23	α Bootis	8h. 12m. to 9h. 2m.	50m.	.001	28-in.	The spectrum is very faint. The evening was misty.
55	Aug. 26	α Aurigæ		48m.	.001	28-in.	Although the evening was clear, the spectrum is faint.
*56	Aug. 28	α Aquilæ Jupiter	10h. 20m. to 12h. 9m.	49m. 50m.	.002 .002	28-in.	A very good picture; the night was quite clear.
*57	Aug. 28	Jupiter α Aurigæ	12h. 45m. to 14h. 18m.	35m. 48m.	.003 .003	28-in.	The spectrum of α Aurigæ is quite faint. To get a strong picture, it would require the slit at .004 or .005, or else two runs of the clock.
58	1881. July 1	Comet *b* α Lyræ	10h. 55m. 14h. 10m.	180m. 10m.		11-in.	The comet's declination at 10h. 45m. was 70°. The slit of the spectroscope was set at right angles to the axis of the tail of the comet. The spectroscope showed a banded spectrum, with the continuous spectrum of the nucleus running through the centre. The photograph shows three bands, a heavy band above H which is divisible into lines, and two faint bands, one between G and *h*, and another between *h* and H.
59	July 2	Moon		8m.	.006	11-in.	There was mist in the sky, which with the low altitude of the moon cut off these spectra above H.
60	July 2	Moon		10m.	.016	11-in.	
61	July 2	Comet α Lyræ	10h. 8m. to 13h. 28m.	196m. 15m.	.016 .016	11-in. 11-in.	There were floating clouds in the sky, and for about 42 m. of its exposure the comet was not visible. At 11h. 20m. the comet's declination was 72½°.
62	July 8	Comet α Lyræ	10h. 55m. to 14h.	228m. 10m.	.016 .011	11-in. 11-in.	Stopped the exposures always before dawn, fearing otherwise that the spectrum of daylight might become superposed on the cometary spectrum. July 7th, took the stellar spectroscope to the laboratory in town, and made a series of carbon arc spectra, with the sun's spectrum on the same plate as a reference spectrum, for comparison with the comet's spectrum. The carbon shows a strong band in the ultra violet.
*63	July 15	α Lyræ Moon	11h. 30m. to 12h. 20m.	34m. 15m.	.002	11-in.	Night became foggy, and the spectra did not extend above H.

TABLE I. — *Continued.*

No.	Date.	Object.	Time.	Expos.	Slit.	Inst.	Remarks.
64	1881–82. July 17	α Scorpii Moon	10h. to 11h. 47m.	90m. 15m.	.005 .005	11-in.	Although the night was unusually clear, there was no impression of the spectrum of α Scorpii. It may have been overlapped by the moon.
*65	July 17	α Lyræ Moon		47m. 20m.	.005 .005	11-in. 11-in.	
66	July 21	α Scorpii α Aquilæ	9h. 44m. to 12h. 7m.	90m. 43m.	.008 .008	11-in.	α Scorpii very faint.
67	July 23	α Aquilæ	11h. 40m. to 12h. 2m.	22m.		11-in.	At 12 h. 2 m. the sky clouded over.
68	July 24	α Scorpii	9h. 17m. to 10h. 56m.	53m.	.004	11-in.	The night was not transparent. The haze in the sky sometimes almost concealed the star.
69	Aug. 8	Moon α Lyræ	9h. 30m. to 10h. 46m.	20m. 49m.	.008 .003	11-in.	Notwithstanding there was a white haze in the sky, these spectra are very sharp.
70	Aug. 12	α Lyræ Moon	10h. 41m. to 11h. 47m.	44m. 20m.	.003 .008	11-in. 11-in.	Night clouded over.
71	Aug. 14	α Scorpii	8h. 27m. to 8h. 45m.	18m.	.006	11-in.	At 8 h. 45 m. the night became cloudy.
72	Aug. 16	α Lyræ Moon	11h. 25m. to 13h. 32m.	46m. 14m.	.003 .003	11-in.	After the exposure of α Lyræ, had to wait an hour for the moon to be high enough to get its spectrum.
73	Aug. 23	α Scorpii α Lyræ	8h. 7m. to 10h. 8m.	64m. 41m.	.008 .008	11-in. 11-in.	The evening was misty, with clouds to the north.
74	Mar. 23	Nebula in Orion	7h. 23m. to 9h. 14m.	111m.		11-in.	This photograph of the spectrum of the Nebula in Orion, and also the one of March 25th, were taken without a slit, and with a direct vision prism in the cone of rays from the objective, before they had reached a focus.
75	Mar. 25	Nebula in Orion	7h. 16m. to 9h. 27m.	131m.		11-in.	
76	Mar. 28	Nebula in Orion	7h. 25m. to 9h. 25m.	120m.	.017	11-in.	This spectrum of the Nebula in Orion and the one of March 30th were taken with the two-prism stellar spectroscope.
77	Mar. 30	Nebula in Orion	7h. 25m. to 9h. 25m.	120m.	.012	11-in.	
*78	1882. Aug. 18	Moon α Aquilæ		1m. 50m.	.012 .004	11-in. 11-in.	This photograph was taken with a spectroscope composed of an Iceland spar prism of two inches aperture, and two quartz lenses of 15 inches focus and also two inches aperture. This spectroscope is much more transparent to the photographic rays than the one with glass lenses and prisms, but it does not give as good definition.

Several of these photographs, as stated above, were taken to the Harvard College Observatory in the spring of 1883, when the measurements described below were made. This work may be divided into three parts: first, the determination of the relative positions of the lines in the various spectra in terms of any convenient unit of length; secondly, from the known spectra of the Moon and Jupiter, a determination of the relation of these measures to wave-lengths; thirdly, a reduction of the measures of the stellar spectra to wave-lengths, and a discussion of the results. The measures were made with the micrometer described in the Annals of Harvard College Observatory, VIII. 42. The photograph was moved under a microscope by a micrometer screw having a pitch of $\frac{1}{24}$ of an inch. By turning the screw, the lines were brought to coincide with the end of a hair in the field of view of the microscope, and the position was determined by the divided head of the screw. As is usual when examining photographs, very low powers were essential, or much of the finer detail would be lost. The best results were attained with an eyepiece and objective, each equivalent to a lens of about 2 inches focus, giving when combined a magnifying power of about fifteen diameters. The uncertainty in the position of the lines of the photograph greatly exceeded the errors of setting and the irregularities of the screw. To establish this point a measurement was made of the divisions of a glass scale constructed by Professor Rogers, in which the errors were wholly inappreciable with so low a magnifying power. Ten divisions were compared, each of which was $\frac{1}{240}$ of an inch, and equalled $\frac{1}{10}$ of a revolution of the screw. The results gave an average deviation of .0015 of a revolution, mainly due to a slight eccentricity of the head of the screw. This eccentricity amounted to about .002 of a revolution. Twelve divisions, each equal to $\frac{1}{24}$ of an inch (one turn of the screw), gave an average deviation of .002 of a revolution. These errors might be still further reduced if required, by taking additional precautions; but they are entirely insensible compared with the uncertainty in the position of the lines in the photograph. They correspond in fact to only about .02 of a ten-millionth of a millimeter in the wave-length. Throughout the work, all the settings were made by turning the screw in the direction in which the readings increase.

The reduction of the measures to wave-lengths was greatly aided by the fact that but little change was made in the spectroscopic apparatus throughout the entire investigation, and that especial care was taken to secure stiffness in its construction. A single curve could thus be used for all the reductions, at least provisionally. On the other hand, it does not seem safe to assume that, when two spectra are photographed side by side on a plate, the lines in each will have the same position.

In some of the photographs, especially in Plates 63 and 65, there is a perceptible want of coincidence between lines which are doubtless in reality of identical origin. No such deviation could be caused by any flexure of the telescope, but it might be due to flexure of the spectroscope when directed towards objects at different altitudes, or to change of temperature of the prisms between successive exposures. It is too great to be attributed to motion of the star in the line of sight.

The measurements have all been reduced to a common zero point by subtracting the reading of the H line from each, and adding 5.000 to avoid negative readings. The H line was selected, since it is common to nearly all the spectra, and is so well marked that an accurate setting can be made on it. This more than compensates for its breadth, which renders it an inconvenient starting-point in the solar spectrum. Any correction for error in setting on this line can better be applied to the final results than to the original measurements.

Since Jupiter and the Moon shine by reflected light, it may be assumed that their spectra are identical with that of the Sun, and that the wave-lengths of the lines in their spectra may therefore be taken from a map of the solar spectrum. On account of errors in the relative prominence of different lines, errors in identification may occur in comparisons with maps made by hand. The photograph of the diffraction spectrum by Dr. Henry Draper (Amer. Journ. Sci., CVI. 401) has therefore been used as the standard to which these measurements are referred. For wave-lengths too great to be contained in this map, Angström's Map (*Recherches sur le Spectre Solaire*, Berlin, 1869) has been employed. Comparison has also been made with the map of Cornu (*Ann. de l'École Normale Supérieure*, Series II., Vol. III.), and those of Vogel (*Publicationen des astrophysikalischen Observatoriums zu Potsdam*, I. 133, II. 83). The unit employed throughout is the ten-millionth of a millimeter, and the results are only carried to single units. The best maps of the solar spectrum differ by as much as one or two of these units in the ultra violet portion, and a greater precision than this in stellar spectra is obviously at present unattainable.

To pass from screw readings to wave-lengths points were constructed with the readings of the spectra of the Moon on Plate 19 as abscissas and the corresponding wave-lengths as ordinates. This plate was selected since the lines appear to be more numerous and better defined than in the other photographs. A smooth curve was then passed through these points. The wave-lengths corresponding to each half-turn of the screw according to this curve are given in Table II., columns 1 and 2. The relation between these quantities may be very closely represented by the formula, $\lambda = 3672 + 39\,n + 4\,n^2$, in which λ denotes the wave-length, and n the number of turns of the screw. The values computed by this formula are given in the third column, and the observed minus the computed values in the fourth column.

TABLE II.

Screw Reading.	Observed.	Computed.	O. — C.	Screw Reading.	Observed.	Computed.	O. — C.
0.0	....	3672	....	5.5	4007	4008	—1
0.5	....	3693	....	6.0	4050	4050	0
1.0	....	3715	....	6.5	4093	4095	—2
1.5	3733	3740	—7	7.0	4140	4141	—1
2.0	3765	3766	—1	7.5	4188	4190	—2
2.5	3795	3795	0	8.0	4240	4240	0
3.0	3828	3825	+3	8.5	4297	4293	+4
3.5	3860	3858	+2	9.0	4350	4347	+3
4.0	3894	3892	+2	9.5	4403	4404	—1
4.5	3930	3929	+1	10.0	4466	4462	+4
5.0	3968	3967	+1				

The close agreement of the formula with observation justifies its use for reducing the observations, since, if any deviation is indicated in the results, a correction may be applied to them. Accordingly the curve represented by this formula was drawn upon a large scale, and the wave-lengths corresponding to each reading were taken from it. In Table III. a comparison is given of all the lines measured in the spectrum of the Moon and of Jupiter. The successive columns give a number for reference, and the original screw readings for the plates whose numbers head the columns, after applying the correction described above, which gives for the H line a reading 5.000 in each spectrum. The readings giving the limits to which the spectra could be traced are omitted in this table, except where they indicate known lines. In the latter case they are indicated by Italics.

TABLE III.

No.	Moon.				Jupiter.				
	21	24	63	65	35	42	43	56	57
1	1.464	....	....	....	....	....	....	....	....
2	1.716	....	....	1.758	....	....	....	....	....
3	1.861	....	....	1.888	....	....	....	....	....
4	2.151	....	....	2.123	....	....	....	....	....
5	....	....	....	2.401	....	....	....	....	....
6	2.554	....	....	2.592	....	....	....	....	....
7	2.833	....	....	2.797	....	....	....	....	....
8	3.203	*3.178*	*3.146*	3.225	*3.204*	....	*3.159*	....	....
9	3.449	....	3.544	3.513	3.547	....	....	....	....
10	....	....	3.697	3.669	3.693	....	....	3.666	3.670
11	....	....	....	3.753	....	....	....	....	....
12	3.882	3.897	....	3.942	3.858	....	3.827	....	....
13	4.168	....	4.151	4.179	4.214	....	....	4.148	4.145
14	4.534	4.558	4.556	4.548	4.557	*4.531*	4.538	4.531	4.544

TABLE III. — *Continued.*

No.	Moon.				Jupiter.				
	21	24	63	65	35	42	43	56	57
15	....	....	....	4.648	....	....	....	....	....
16	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
17	....	....	....	....	5.193	....	....	....	....
18	....	....	5.345	....	5.353	....	....	....	5.337
19	....	....	5.475	5.464	5.496	....	....	5.476	5.463
20	5.804	....	5.786	5.787	5.814	....	5.780	5.805	5.768
21	....	....	5.946	5.942	5.964	....	5.959	5.951	5.944
22	....	....	6.161	6.162	6.187	....	6.151	6.169	6.063
23	....	....	....	....	....	....	....	....	6.288
24	....	....	....	6.326	6.337	....	6.320	6.335	6.317
25	6.599	6.592	6.577	6.581	6.605	6.578	6.584	6.579	6.576
26	....	6.661	....	....	....	....	....	....	....
27	....	....	6.925	6.919	6.944	....	6.898	6.921	6.918
28	....	....	....	....	....	....	....	....	6.985
29	....	....	7.046	7.038	7.044	....	....	7.042	7.026
30	....	7.143	7.189	7.171	7.178	....	....	7.192	7.163
31	7.383	7.406	7.368	7.326	7.369	....	7.348	7.359	7.330
32	....	....	....	....	7.500	....	....	....	7.493
33	7.644	....	7.637	7.606	7.616	....	....	7.616	7.610
34	....	....	....	....	....	....	....	....	7.707
35	....	....	....	7.755	7.775	....	....	7.783	7.776
36	7.923	7.890	7.885	7.863	7.881	....	7.874	7.885	7.874
37	....	7.990	7.985	7.983	7.972	....	....	7.991	7.972
38	....	....	8.087	8.069	8.097	....	....	8.104	8.097
39	....	....	8.211	8.199	8.194	....	....	8.205	8.202
40	....	8.334	8.317	8.295	8.304	....	8.331	8.324	8.311
41	....	....	8.482	....	8.478	....	....	8.480	8.456
42	....	....	8.593	8.564	8.577	....	8.596	8.578	8.568
43	8.678	8.680	8.661	8.682	8.648	8.636	8.644	8.654	8.660
44	....	....	8.784	8.768	8.785	....	8.798	8.791	8.785
45	....	8.925	8.927	8.910	8.923	8.938	8.925	8.929	8.923
46	....	9.043	9.028	....	....	....	....	9.040	9.032
47	....	....	9.222	9.222	9.204	....	....	....	....
48	9.353	9.347	9.300	....	9.300	....	9.322	9.292	9.294
49	....	....	9.494	9.440	9.472	....	....	9.474	9.465
50	....	....	....	....	9.547	....	....	9.566	9.556
51	....	....	....	....	9.677	....	....	9.714	9.706
52	9.936	9.944	9.905	9.891	9.867	....	9.898	9.881	9.880
53	....	....	....	....	10.059	....	....	10.082	10.073
54	10.511	10.427	....	10.423	10.416	....	....	10.441	10.338
55	....	....	....	....	....	....	....	10.621	10.586

In Table IV. these measures are compared. The first column gives the same number for reference as in Table III. The second column gives the wave-lengths of the lines in the solar spectrum, with which the lines here measured are assumed to be identical. Each measurement is reduced to wave-lengths by the formula given above. The residuals found by subtracting the assumed wave-lengths from these are given in the subsequent columns. Each plate is designated by its appropriate number.

TABLE IV.

No.	Wave Length.	Moon.				Jupiter.				
		21	24	63	65	35	42	43	56	57
1	3736	0	....	....	....	....	....	....	....	....
2	3750	0	....	....	+2	....	....	....	....	....
3	3759	—1	....	....	+1	....	....	....	....	....
4	[3774]	[+1]	....	....	[—1]	....	....	....	....	....
5	3786	....	....	....	+3	....	....	....	....	....
6	3801	—8	....	....	0	....	....	....	....	....
7	3816	—1	....	....	—3	....	....	....	....	....
8	3841	—3	—5	—7	—1	—3	....	—5	....	....
9	3859	—5	....	+2	0	+2	....	....	....	....
10	3872	....	....	—1	—3	—2	....	....	—3	—8
11	3878	+1	+2	....	—3	—1	....	—8	....	....
12	3888			....	0		....		....	....
13	3905	0	....	—2	0	+3	....	....	—2	—2
14	3933	—1	+1	+1	0	+1	—1	—1	—2	—1
15	3943	....	....	....	—3	....	....	....	....	....
16	3967	0	0	0	0	0	0	0	0	0
17	3988	....	....	....	....	—5	....	....	....	....
18	3998	....	....	—3	....	—2	....	....	....	—4
19	4005	....	....	+1	0	+3	....	....	+1	0
20	4032	+1	....	0	0	+2	....	—1	+1	—2
21	4045	....	....	0	0	+2	....	+1	0	0
22	4063	....	....	+1	+1	+3	....	0	+2	—7
23	4071	....	....	....	....	....	....	....	....	0
24	4077	....	....	....	+2	+8	....	+1	+3	+1
25	4101	+3	+3	+1	+2	+4	+1	+2	+2	+1
26	4118	....	—8	....	....	....	....	....	....	....
27	4133	....	....	+1	+1	+8	....	—1	+1	0
28	4138	....	....	....	....	....	....	....	....	+2
29	4143	....	....	+2	+2	+2	....	....	+2	—3
30	4155	....	0	+4	+3	+3	....	....	+5	+2
31	4172	+6	+8	+4	+1	+5	....	+3	+4	+1
32	4187	....	....	....	....	+3	....	....	....	+2
33	4201	+4	....	+8	0	+1	....	....	+1	0
34	4210	....	....	....	....	....	....	....	....	+1
35	4215	....	....	....	+2	+4	....	....	+5	+4
36	4226	....	+5	+4	+2	+4	....	+4	+4	+3
37	4236	—1	+6	+5	+5	+4	....	....	+6	+4
38	4250	....	....	+2	+1	0	....	....	0	0
39	4260	....	....	+6	+5	0	....	....	+1	+1
40	4271	....	—2	—4	—6	+1	....	+4	+8	+2
41	4289	....	....	+2	....	+1	....	....	+2	0
42	4301	....	....	+2	—1	0	....	+3	+1	0
43	4312	0	+1	—1	—5	—3	—4	—3	—2	—2
44	4324	....	....	0	—2	0	....	+1	+1	0
45	4339	....	0	0	—2	0	+1	0	+1	0
46	4351	....	+1	—1	....	....	....	....	0	0
47	4375?	....	....	—3	—2	—5	....	....	....	....
48	4383	+8	+3	—2	....	—3	....	0	—3	—3
49	4404	....	....	—1	—8	—4	....	....	—4	—5
50	4414	....	....	....	....	—5	....	....	—3	—3
51	4424	....	....	....	....	—1	....	....	+5	+4
52	4454	+2	+3	—2	—3	—7	....	—8	—7	—7
53	4483	....	....	....	....	—12	....	....	—9	—11
54	4530	—3	—14	....	—13	—15	....	....	—12	—26
55	4549	....	....	....	....	....	....	....	—9	—18

Plate 42 was one of the first to be measured, and only the most conspicuous lines were observed. This was done with the intention of determining the scale from a few well-defined lines. It was afterwards deemed better to employ all the lines visible on each plate for this purpose. No marked line in the solar spectrum satisfactorily represents No. 4 of Table IV. Nos. 3 and 4, 5 and 6, and 7 and 8, are designated in the original record as the limits of transparent bands in the negatives, that is, of dark bands in the spectrum. Nos. 11 and 12 appeared as a broad dark band, whose edges were observed in Plate 65, and its centre in Plates 21, 24, 35, and 43. No. 28 is recorded in Plate 57 as the centre of the band extending from 27 to 29. No. 47 is not well identified. The photographs of the solar spectrum indicate a line having $\lambda = 4375$ as the most conspicuous in this vicinity.

The residuals in Table IV. must next be examined, to see if they indicate any systematic deviation, or if any correction should be applied to the wave-lengths as deduced by the formula $\lambda = 3672 + 39n + 4n^2$.

TABLE V.

λ	Moon.				Jupiter.				All.		
	No.	$\Sigma +$	$\Sigma -$	$\frac{\Delta \pm}{n}$	No.	$\Sigma +$	$\Sigma -$	$\frac{\Delta \pm}{n}$	$\frac{\Delta \pm}{n}$	Curve.	$\frac{\Sigma \pm}{n}$
3700	3	2	0	+0.7	0	..	...	.....	+0.7	+0.5	0.7
3800	11	4	24	—1.8	2	0	8	— 4.0	—2.0	—1.0	2.4
3900	17	7	18	—0.6	14	6	21	— 1.1	—0.8	—0.8	1.5
4000	12	2	3	—0.1	19	10	14	— 0.2	—0.2	—0.1	1.3
4100	12	19	8	+0.9	22	33	11	+ 1.0	+1.0	+1.0	1.5
4200	20	67	1	+3.3	26	73	0	+ 2.8	+3.0	+2.2	1.9
4300	17	16	21	—0.3	28	23	14	+ 0.3	+0.1	+0.7	1.6
4400	9	7	17	—1.1	16	9	89	— 1.9	—1.6	—2.6	2.2
4500	7	5	35	—4.8	12	0	132	—11.0	—8.5	—7.4	4.6

In Table V. they are arranged in groups extending from 3750 to 3850, 3850 to 3950, etc. The first column gives the approximate mean wave-length of each group, and the next four columns give for the Moon the number of measurements included in each group, the sum of the positive and the sum of the negative residuals, and their algebraic mean. The next four columns give the corresponding quantities for Jupiter. The last three columns relate to the observations of the Moon and Jupiter, without distinction. The first of these columns gives the algebraic mean of all the residuals, and indicates the observed deviation from the computed wave-lengths. A curve was drawn to represent this deviation, and its ordinates are given in the next column. Finally, the residuals were all corrected by means of this curve according to the system indicated in Table VI., and the arithmetical mean of the residuals is given in the last column. The residuals of the H line, being all rendered zero by the method of reduction, are not included in the last column, although retained in the preceding columns.

The average deviation of all the measures, including the faint, as well as the more marked lines, is only 1.7, or less than $\frac{1}{3}$ of the interval between the sodium lines. Less accuracy was attained in measuring the lines near the ends of the spectrum, owing to the faintness of the photographic effect. In many cases the last lines were marked as "very doubtful." This error was increased for the lines of greater wave-length by the fact that a given distance, as one division of the screw, represents a change in wave-length of double the corresponding amount at the other end of the spectrum. Without the correction indicated by this table, the average deviation of the individual results would be 2.7. Table VI. gives the correction indicated in each portion of the spectrum derived from Table V. The first column gives the limiting wave-lengths within which the corrections in the second column should be applied. The sign of the corrections is such that they are to be added to the results derived from the formula.

TABLE VI.

Limits.	Correction.	Limits.	Correction.
3700 to 3757	0	4398 to 4421	+ 3
3758 " 3952	+1	4422 " 4443	+ 4
3953 " 4054	0	4444 " 4464	+ 5
4055 " 4126	—1	4465 " 4484	+ 6
4127 " 4264	—2	4485 " 4503	+ 7
4265 " 4308	—1	4504 " 4521	+ 8
4309 " 4342	0	4522 " 4539	+ 9
4343 " 4371	+1	4540 " 4556	+10
4372 " 4397	+2		

Measurements of these spectra may then be converted into wave-lengths by applying to the readings of the curve described above the corrections of Table VI. Thus the measurement 2.618 gives by the curve 3802, but since this falls between 3758 and 3952, we must apply the correction +1. The wave-length corresponding to 2.618 will then be 3803. When the same lines are observed in several spectra, the correction may be applied to their mean, instead of to the separate readings.

Plates 21, 23, and 24 were taken with the 12-inch refractor, and accordingly the spectra are narrow in the violet and wide in the blue portions. For Plates 63, 65, 73, and 78 the 11-inch telescope was employed. As this instrument is corrected for the photographic rays, the spectra are of nearly uniform width, becoming slightly narrower at the ends. The other plates measured were obtained with the 28-inch reflector. As such an instrument is free from chromatic aberration, the spectra are of uniform width.

The measurements of the various spectra are given in Table VII. The first column gives a number for reference, followed by the measures of the corresponding lines in the columns headed by the number of the plates. The second part of each portion of the table gives the mean wave-length of each line, found by reducing the corresponding measures to wave-lengths by means of the curve and correcting by Table VI. The last columns give the residuals found by subtracting the mean from the individual values. So many measures were made of *a Lyræ* that the second part of the table is here separated from the first. In Plate 73 the residuals are omitted, since the scale for this plate differs from that of the others. In the spectra of *a Scorpii* on Plate 73 the H line is not visible. The original readings are therefore given in Table VII.

TABLE VII.

a AQUILÆ.

No.	41	42	56	λ	41	42	56
1	*1.517*	*1.470*	....	3738	+1	—1	....
2	1.793	1.765	....	3754	0	—1	....
3	2.104	2.089	....	3773	0	—1	....
4	2.539	2.542	....	3798	0	0	....
5	3.129	3.150	....	3835	—1	+1	....
6	3.904	3.914	3.929	3887	—1	0	+1
7	4.540	4.541	4.552	3933	0	0	+1
8	5.000	5.000	5.000	3967	0	0	0
9	....	5.770	....	4030	....	0	....
10	6.576	6.573	6.595	4102	—1	—1	+1
11	8.936	9.912	8.937	4339	—1	+1	+1

a LYRÆ.

No.	26	30	34	45	46	63	65	73
12	*1.308*	....	....	....	....	....	....	....
13	1.520	*1.503*	*1.525*	*1.422*	....	....	....	*0.863*
14	1.787	1.772	1.839	1.735	....	....	*1.733*	1.211
15	2.114	2.116	2.156	2.068	....	....	....	1.605
16	2.554	2.573	2.580	2.504	*2.539*	....	2.563	2.121
17	3.121	3.128	3.154	3.118	3.152	3.138	3.149	2.890
18	3.925	3.918	3.954	3.914	3.900	3.911	3.935	3.732
19	4.517	....	4.536	4.502	4.519	4.509	4.544	4.437
20	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
21	6.565	6.562	6.560	6.569	6.586	6.575	6.559	6.832
22	8.882	8.893	8.881	8.916	8.922	8.918	8.913	9.508
23	....	....	....	....	....	....	....	13.595

TABLE VII. — *Continued.*

a Lyræ.

No.	λ	26	30	34	45	46	63	65
12	3728	0	....	....	....	....	....	....
13	3738	+1	0	+1	—4	....	....	....
14	3753	+1	0	+4	—2	....	....	—2
15	3773	0	0	+3	—2	....	....	....
16	3799	0	+1	+2	—3	—1	....	+1
17	3835	—1	—1	+1	—2	+1	0	+1
18	3888	0	—1	+2	—1	—2	—1	+1
19	3932	0	....	+1	—3	0	—1	+1
20	3967	0	0	0	0	0	0	0
21	4102	—1	—1	—1	0	+1	0	—1
22	4337	—2	—1	—3	+1	+2	+1	+2
23	4861	....	....	....	....	....	....	....

a Aurigæ.

No.	21	43	57	λ	21	43	57
24	....	3.600	....	3865	....	0	....
25	*4.532*	4.528	*4.545*	3932	0	0	+1
26	5.000	5.000	5.000	3967	0	0	0
27	....	5.494	....	4008	....	0	....
28	....	5.832	5.770	4032	....	+3	—2
29	....	5.970	5.918	4045	....	+2	—2
30	....	6.323	6.281	4076	....	+2	—2
31	6.588	6.600	6.568	4102	0	+1	—2
32	....	6.929	6.978	4134	....	—2	+3
33	....	7.171	7.160	4156	....	0	—1
34	7.347	7.392	7.328	4174	—1	+3	—3
35	7.627	7.644	7.549	4199	+3	+4	—6
36	....	7.777	7.737	4214	....	+3	—2
37	7.910	7.881	7.854	4228	+3	0	—2
38	....	....	7.985	4239	....	....	0
39	....	....	8.090	4251	....	....	0
40	....	8.202	8.174	4262	....	+1	—2
41	....	8.357	8.290	4269	....	—1	+1
42	....		8.463	4287	....		+1
43	....	....	8.567	4299	....	....	0
44	8.638	8.660	8.626	4307	0	+2	—1
45	....	....	8.756	4321	....	....	0
46	8.976	8.940	8.902	4341	+4	0	—4
47	....	9.091	[8.801]	4358	....	0	[+1]
48	....	9.342	9.259	4382	....	+5	—4
49	....	....	9.450	4401	....	....	0
50	....	9.747	....	4438	....	0	....
51	9.948	9.952	....	4462	0	0	....
52	....	10.187	....	4493	....	0	....
53	10.390	10.456	....	4524	—5	+4	....
54	....	10.641	....	4552	....	0	....

The record of No. 47, Plate 57, gives a reading of 8.801; but this is evidently wrong, since it is less than No. 46. It should perhaps have been 9.101, which gives a residual +1.

TABLE VII. — *Continued.*

α Bootis.

No.	23	24	32	λ	23	24	32
55	....	....	*2.892*	3819	....	....	0
56	....	....	3.245	3842	....	....	0
57	....	....	3.508	3859	....	....	0
58	....	*3.765*	3.816	3878	....	—2	+2
59	....	....	4.122	3902	....	....	0
60	*4.532*	4.552	4.554	3933	—1	+1	+1
61	5.000	5.000	5.000	3967	0	0	0
62	....	....	5.347	3995	....	....	0
63	5.508	....	5.480	4007	+1	....	—1
64	5.830	....	5.801	4034	+1	....	—1
65	5.976	....	5.938	4046	+2	....	—1
66	6.085	....	6.113	4057	—1	....	+2
67	....	....	6.261	4072	....	....	0
68	6.368	6.345	6.324	4080	+1	0	—2
69	6.388	....	....	4084	0	....	....
70	6.530	6.561	6.540	4098	—1	+2	0
71	....	....	6.737	4116	....	....	0
72	....	....	6.917	4131	....	....	0
73	7.088	7.098	7.039	4146	+1	+2	—3
74	7.300	7.380	7.335	4172	—4	+4	0
75	....	....	7.612	4199	....	....	0
76	7.716	....	7.742	4212	—2	....	+1
77	7.830	7.827	7.855	4224	—1	—2	+2
78	7.938	7.932	7.965	4234	0	0	+1
79	8.162	....	8.100	4254	+1	....	—2
80	8.384	....	8.299	4275	+4	....	—4
81	8.647	8.615	8.613	4306	+2	—1	—2
82	....	....	8.795	4325	....	....	0
83	8.875	....	8.890	4334	0	....	+1
84	8.993	....	9.018	4349	—2	....	+1
85	9.274	9.263	9.292	4383	—4	+5	—2
86	9.551	....	9.460	4407	+6	....	—5
87	9.927	9.969	9.880	4460	0	+5	—6
88	....	....	10.160	4489	....	....	0
89	10.417	10.382	10.388	4520	+3	—2	—1

α Scorpii.

No.	39	48	73	λ	39	48
90	....	....	50.449	3976	....	....
91	....	....	52.126	4099	....	....
92	6.951	6.876	....	4132	+4	—4
93	....	7.175	....	4156	....	0
94	7.345	7.226	52.988	4169	+3	—8
95	7.542	7.552	53.346	4202	—9	—8
96	....	7.718	53.486	4212	....	—2
97	....	....	53.632	4224	....	....
98	....	7.927	53.720	4233	....	0
99	....	....	53.804	4242	....	....
100	8.057	8.058	53.942	4253	—5	—5
101	8.308	8.239	54.122	4270	+1	—6
102	....	8.390	54.221	4280	....	0

TABLE VII. — *Continued.*

a SCORPII.

No.	39	48	73	λ	39	48
103	8.477	....	54.304	4291	—1	....
104	8.598	8.543	54.393	4296	+7	+1
105	....	8.650	54.548	4312	....	—2
106	....	....	54.658	4320	....	....
107	....	....	54.718	4328	....	....
108	8.925	8.925	54.811	4336	+3	+3
109	....	....	54.864	4342	....	....
110	....	....	54.932	4349	....	....
111	....	9.087	55.019	4360	....	—3
112	....	....	55.078	4366	....	....
113	....	....	55.150	4374	....	....
114	....	....	55.216	4382	....	....
115	9.591	9.535	55.474	4410	+8	+1
116	....	9.754	55.718	4440	....	—2
117	....	....	55.787	4448	....	....
118	....	10.033	55.921	4464	....	+4
119	10.111	....	56.037	4477	+4	....
120	....	....	56.138	4490	....	....
121	....	....	56.327	4513	....	....
122	....	10.517	56.522	4539	....	—5
123	....	....	56.574	4544	....	....
124	10.865	....	56.751	4567	+12	....
125	....	....	57.148	4617	....	....
126	....	....	57.475	4658	....	....
127	....	....	57.610	4676	....	....

The measures of the different photographs of the first four stars agree as well as could be anticipated. The accidental errors are small considering the extreme faintness of many of the images. No large systematic deviations appear, except in the case of *a Lyræ*, Plate 73, to which reference has already been made (p. 253). Small systematic errors are, however, perceptible in other plates, as in No. 34, where the residuals change from positive to negative, and in No. 45, where they change from negative to positive. They will not, however, sensibly affect the final result, and scarcely justify the application of a separate correction.

A comparison of the lines in *a Aquilæ* * and *a Lyræ* is given in

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* A peculiarity of the spectrum of *a* Aquilæ deserves special mention. Besides the intense broad hydrogen bands which characterize the spectrum of *a* Lyræ and similar stars, it exhibits a multitude of very fine lines, which are easily seen between G and H in several of the plates, but are too delicate to be satisfactorily measured. Dr. Draper considered these fine lines very important, as showing that this star — Altair — should be considered a sort of intermediate link between *a* Lyræ and Sirius on one side, and Capella and the Sun on the other. — C. A. Y.

Table VIII. The columns give a number for reference, the result for α *Aquilæ* taken from Table VII., that for α *Lyræ*, and that given by Dr. Huggins for all stars of this class.

TABLE VIII.

No.	Dr. Draper.		Dr. Huggins.		Dr. Draper.		Dr. Huggins.
	α Aquilæ.	α Lyræ.	Type I.		α Aquilæ.	α Lyræ.	Type I.
1	....	....	3699	8	3835	3835	3834
2	....	....	3708	9	3887	3888	3887
3	....	3728	3717	10	3933	3932	....
4	3738	3738	3730	11	3967	3967	3968
5	3754	3753	3745	12	4030	....	....
6	3773	3773	3768	13	4102	4102	4101
7	3798	3799	3795	14	4339	4337	4340

The distinctive feature of these spectra is a series of broad dark lines at regular intervals. The lines of greater wave-length appear to coincide with the hydrogen lines, and the interval between the successive lines continues to diminish with the wave-length. Twelve of these lines are photographed by Dr. Huggins. To these we should add the lines F (4861) and C (6562), which are beyond the limits of the photograph. The first and second lines are not contained in Dr. Draper's photographs, as his plates were not sensitive to rays of such short wave-length. Line 10, which appears to coincide with K of the solar spectrum, is as strong as the others in α *Aquilæ*, but in every photograph of α *Lyræ* was marked as faint. In one case in Plate 30 it was overlooked. This photograph was over-exposed in this part of the spectrum, but a more careful examination shows that the line is probably present. Line 10 was only noticed in Plate 42.

The resemblance of the spectrum of α *Aurigæ* to that of the Sun has already been noted; α *Bootis* appeared to belong to the same class, but the identity of the lines was not perceived until the measurements had been reduced. It then became obvious that this star also has a spectrum closely resembling the Sun. The comparison is made in Table IX. The first and second columns are the same as in Table IV., and give a number for reference and the wave-length of the lines in the solar spectrum. The next column gives the number of plates of the Moon and Jupiter, on which each line was measured. It therefore gives a sufficiently good comparison of the relative prominence of each line. The next four columns give for the *Moon*, for *Jupiter*, for α *Aurigæ*, and for α *Bootis*, the mean of the measured wave-length minus the wave-length given in the second column.

TABLE IX.

No.	Wave Length.	No.	Moon.	Jupiter.	a Aurigæ.	a Bootis.
1	3736	1	0	....	....	....
2	3750	2	+1	....	....	....
3	3759	2	+1	....	....	....
4	[3774]	2	+1	....	....	....
5	3786	1	+4	....	....	....
6	3801	2	—1	....	....	....
7	3816	2	—1	....	....	+3
8	3841	4	—8	....	....	+1
9	3859	4	0	+8	....	0
10	3872	5	—1	—2	....	....
11	3878	5	+4	+3	....	0
12	3888	5	+1	+2	....	....
13	3905	6	0	+1	....	—3
14	3933	9	+1	0	—1	0
15	3943	1	—2	....	....	....
16	3967	9	0	0	0	0
17	3988	1	....	—5	....	....
18	3998	3	—3	—3	....	—3
19	4005	5	+1	+1	+3	+2
20	4032	7	0	0	0	+2
21	4045	6	0	+1	0	+1
22	4063	6	0	—1	....	—6
23	4071	1	....	—1	....	—1
24	4077	5	+1	+1	—1	+8
25	4101	9	+1	+1	+1	—3
26	4118	1	—9	....	....	—2
27	4133	6	0	0	+1	—2
28	4138	1	....	0	....	....
29	4143	5	0	—2	....	+3
30	4155	6	0	+1	+1	....
31	4172	8	+3	+1	+2	0
32	4187	2	....	0	....	....
33	4201	6	0	—1	—2	—2
34	4210	1	....	—1	....	+2
35	4215	4	0	+2	—1	....
36	4226	7	+2	+2	+2	—2
37	4236	7	+2	+3	+3	—2
38	4250	5	0	—2	+1	+4
39	4260	5	+4	—1	+2	....
40	4271	7	—5	+1	—2	+4
41	4289	4	+1	0	—2	....
42	4301	6	—1	0	—2	....
43	4312	9	—1	—3	—5	—6
44	4324	6	—1	0	—3	+1
45	4339	8	—1	0	+2	—5
46	4351	4	+1	+1	+7	—2
47	4375?	3	0	—8	....	....
48	4383	7	+3	0	—1	0
49	4404	5	—1	—1	—3	+3
50	4414	8	....	—1	....	....
51	4424	3	....	+7	+14	....
52	4454	8	+5	—1	+ 8	+6
53	4483	3	....	—5	+10	+6
54	4530	6	+1	—9	—6	—10
55	4549	2	....	—1	+3	....

The only line omitted in this table which was noted in the spectra of *a Aurigæ* or *a Bootis* is No. 69 of Table VII. This line was measured in Plate 23 as one edge of a dark band in the negative, No. 70, or *h*, forming the other side. Its wave-length may therefore be taken as about 4090. This is the bright band noted on page 242. The same phenomenon is shown in Plate 24, and even better in Plate 32. It is also noticeable, though in a less marked manner, in the solar spectrum, as is shown in the photographs of Jupiter and of the Moon.

Not only do the lines of *a Aurigæ* and *a Bootis* appear to coincide with those of the Sun in position, but their relative intensity seems to be nearly the same. Of the twelve lines seen in at least seven of the nine spectra of the Moon and Jupiter, every one is contained in the spectra of both *a Aurigæ* and *a Bootis*. Of the fifteen lines which are so faint as to be contained in but one or two of the spectra of the Moon or Jupiter, only four are contained in the spectrum of *a Bootis*, and but one in that of *a Aurigæ*. The evidence afforded by these photographs, therefore, points very strongly to the conclusion that the spectra of these stars, and consequently their constitution, are the same as that of our Sun.

The measurements of *a Scorpii* are much less satisfactory than those of the other stars. Plate 73 gives a large number of lines, but the scale of this plate, as already stated, differs from that of the others. Fortunately, *a Lyræ* was photograped on the same plate, and a curve was accordingly constructed with the measurements of the lines of this star as abscissas, and the wave-lengths taken from the measures of the other plates as ordinates. By this curve the measures of *a Scorpii* were reduced. Plates 39 and 48 were taken with a wide slit, and the lines are indistinct. A satisfactory comparison could scarcely be made without preparing enlarged paper positions, and marking on them the points measured. This seems scarcely advisable, considering the superiority of Plate 73. The large residuals render the identification uncertain in some cases, since any line would fall near one of those in Plate 73. The correspondence is much less marked than in the other stars.

A comparison of the measures of the various plates is given in Table X. The first column gives the number of the plate; the second, the name of the object photographed; the third, the number of measures made, that is, the number of points of the spectrum noted; and the fourth column gives the quantity subtracted from each of the measures to reduce them to the same zero. The measures of the ends of the spectra are given in the next two columns, followed by the reduced value in wave-lengths.

TABLE X.

No. of Plate.	Object.	No. of Measures.	Zero.	Measures.		Wave-Lengths.	
				Beginning.	Ending.	Beginning.	Ending.
21	α Aurigæ	11	45.184	*4.532*	11.374	3932	4650
	Moon	24	45.173	0.951	11.898	3708	4737
23	α Bootis	24	45.281	*4.532*	11.465	3932	4664
24	α Bootis	15	45.341	*3.765*	11.334	3876	4644
	Moon	18	45.184	*3.178*	12.074	3836	4749
26	α Lyræ	12	51.328	*1.308*	12.714	3728	4843
30	α Lyræ	10	48.686	*1.503*	13.065	3738	4896
32	α Bootis	36	45.032	*2.892*	12.419	3819	4799
35	Jupiter	42	45.100	*3.204*	12.091	3838	4751
34	α Lyræ	11	49.798	*1.525*	12.215	3739	4770
39	α Scorpii	12	41.272	4.870	11.368	3957	4650
41	α Aquilæ	11	68.613	*1.517*	11.179	3739	4622
42	α Aquilæ	12	53.313	*1.470*	12.264	3737	4776
	Jupiter	6	53.308	*4.531*	11.888	3836	4721
43	α Aurigæ	26	46.215	*3.600*	11.821	3865	4713
	Jupiter	20	46.181	*3.159*	12.295	3932	4780
45	α Lyræ	11	47.572	*1.422*	11.970	3734	4735
46	α Lyræ	8	45.517	2.539	11.689	3798	4694
48	α Scorpii	19	43.441	6.691	11.209	4113	4628
56	α Aquilæ	7	45.489	3.310	11.546	3846	4674
	Jupiter	37	45.551	3.230	12.126	3841	4755
57	Jupiter	12	44.848	3.476	11.385	3857	4651
	α Aurigæ	25	44.862	*4.545*	12.338	3932	4786
63	α Lyræ	8	45.123	2.657	11.599	3805	4681
	Moon	34	45.032	*3.146*	12.094	3834	4750
65	α Lyræ	9	45.040	*1.733*	12.001	3751	4738
	Moon	42	44.991	1.525	12.045	3739	4744
73	α Scorpii	37	45.316	5.133	13.272	3976	4820
	α Lyræ	11	45.316	*0.863*	*13.595*	3728	4861
78	α Aquilæ	10	43.546	0.080	24.069	....	....

The readings in the sixth column cannot be reduced to wave-lengths directly, since they fall outside of the limits of Table VI. The curve on which this table was based was accordingly prolonged, and a curve drawn giving for large readings the corresponding wave-lengths. In the columns of Table XI. these values are given for intervals of half a turn of the micrometer screw.

TABLE XI.

No. of Turns.	Wave-Length.	No. of Turns.	Wave-Length.
10.0	4468	12.0	4737
10.5	4532	12.5	4811
11.0	4597	13.0	4886
11.5	4666		

The readings in the fourth column of Table X. serve to test the flexure of the spectroscope by showing whether the zero was the same in the various spectra on the same plate. A portion of the difference may be due to the impossibility of setting the lines exactly at right angles to the micrometer screw, and in some cases, as in Plate 56, to a possible movement of the plate between the measures of the two spectra. This cannot account for all the difference, however, since in several cases it is obvious to the eye. The difference in wave-length would vary in different parts of the spectrum, but an idea of its magnitude may be inferred by the rule that one turn of the screw near the H line corresponds to a change of 80 in the wave-length. The two spectra are thus displaced by several units, an amount which the residuals show is quite beyond the accidental errors of measurement. The adoption of a new zero for each spectrum thus appears to have been entirely justified.

From the last two columns of Table X. we see that the plates are sensitive to rays of light of wave-lengths 3750 to 4800, that is, from M nearly to F. When the light is intense, the spectra extend beyond these limits. F is photographed in Plate 73, and in Plate 21 a line marked "very doubtful" was observed at 3708. It was not included in Tables III. and IV., as it probably only indicates the beginning of the spectrum.

To secure entire independence in the results, the measures were completed before the reductions were begun. The lines in each plate were measured without comparison with any map, and no search was made for lines which appeared to be wanting. When two similar spectra were photographed side by side, as in Plate 21, care was taken to cover one when measuring the other. Under these circumstances, the agreement in the measures of several plates is strong evidence of the identity of the spectra.

[From the American Journal of Science and Arts, Vol. XVIII., Dec., 1879.]

On Photographing the Spectra of the Stars and Planets.

By Henry Draper, M. D.

[Read before the National Academy of Sciences, Oct. 28, 1879.]

For many years it has seemed probable that great interest would be attached to photographs of the spectra of the heavenly bodies, because they offer to us conditions of temperature and pressure that cannot be attained by any means known at present, on the earth. The especial point of interest is connected with considerations regarding the probable non-elementary nature of the so-called elementary bodies. There has long been a suspicion in the minds of scientific men that one or more truly elementary bodies would be found from which those substances which have not as yet been decomposed are formed. The recent publications of Lockyer have attracted particular attention to this topic.

The most promising laboratory processes for accomplishing the dissociation of our present elements depend upon the action of heat, especially when accompanied by electrical influences, and upon relief of pressure. But the temperature we can employ is far below that found in the stars, which is comparable only with the heat of our Sun, and when in addition the application of heat is restricted by the narrow range of circumstances under which we can also reduce the pressure, complete success seems to be impracticable in the laboratory.

But in the stars, nebulæ, and comets there is a multitude of experiments all ready performed for us with a variety of conditions of just the kind we need. It remains for us to observe and interpret these results, and this is the direction I have sought to pursue.

There is but one mode of investigation that can add materially to the knowledge Astronomy has given us of the heavenly bodies; that is the spectroscopic. This in its turn is capable of a subdivision into two methods, one by the eye, the other by photography. Each of these has its special advantages and each its defects. The eye sees most easily the middle regions of the spectrum, and can appreciate exceedingly faint spectra; by the aid of micrometers it can map with precision the position of the Fraunhofer lines, and by estimation it can with tolerable accuracy approximate to the relative strength, breadth, and character of these lines. The character of the spectrum lines is however of great value for the purposes we are now speaking of, and the greatest precision is needed. Photography, on the other hand, as applied to faint spectra, deals mainly with the more refrangible region, and cannot at present be employed in stellar work below the line F. Fortunately there is no break in the spectrum between the place where the eye leaves off and photography begins, and hence the two methods lend one another mutual assistance. The photograph, when suitably accommodated with a standard reference spectrum from some known source, gives valuable indications as to the positions and all the peculiarities of the lines.

But the application of photography to the taking of stellar spectra is surrounded by obstacles. These are partly due to the small quantity of light to be dealt with, and partly to the fact that it is necessary to overcome the motion of the earth, and other causes, such as atmospheric refraction, which seem to make a star change its place continually. The exposures of the sensitive plate require to be sometimes for two hours, even with a large telescope, and if during that time the image of the star at the focus of the telescope has changed place $\frac{1}{300}$ of an inch, the light no longer falls on the slit of the spectroscope. The changes of the earth's atmosphere in regard to photographic transparency as well as by fog also offer impediments, and promote the chances of failure. There is often a yellow condition of the air, which may increase the length of exposure required forty times or more.

It will, from what has been said above, be readily perceived that a research such as this consumes a great deal of time; in fact, these experiments and the preparations for them have extended over more than twelve years. A large telescope is required, and for many reasons the reflector at first seems most suitable. Recently, however, I have found that the refractor has also some special advantages.

In 1866 I had already constructed a silver glass reflector of 15½ inches aperture, which was commenced in 1858, and had taken with it many hundreds of photographs of the Moon. But as the mounting had been contrived for lunar photography and to avoid the Moon's motion in declination, the instrument was not suitable for the spectroscopic work contemplated. A reflector of twenty-eight inches aperture was therefore commenced in 1866, and in 1871 it was ready for use.

On May 29th, 1872, my first photograph of the spectrum of a star was taken, the spectrum of Vega being photographed by the aid of a quartz prism. At this time I did not happen to know that Dr. Huggins, who is so distinguished for his thorough and accurate researches on the visible portion of the spectra of the heavenly bodies, had already made some attempts in this direction, as is shown by the following paragraph from the Transactions of the Royal Society for 1864: "On the 27th of February, 1863, and on the 3d of March of the same year, when the spectrum of Sirius was caused to fall upon a sensitive collodion surface, an intense spectrum of the more refrangible part was obtained. From want of accurate adjustment of the focus, or from the motion of the star not being exactly compensated by the clock movement, or from atmospheric tremors, the spectrum, though tolerably defined at the edges, presented no indications of lines. Our other investigations have hitherto prevented us from continuing these experiments farther; but we have not abandoned our intention of pursuing them."

During August, 1872, I took several photographs of the spectrum of Vega, and these showed four strong lines at the more refrangible end of the spectrum, the least refrangible being near G. On pursuing the subject, and seeking to ascertain what substances gave rise to these lines, it became obvious that a photographic study of this part of the spectrum for the metals and non-metals was necessary to interpret the results. This of course opened out a large field for experiment, requiring many years for its study, and hence, as several physicists were engaging in the study of the spectra of the metals, I concluded to discontinue the experiments commenced in 1870 on the spectra of the metals, and to confine the investigation mainly to the non-metals. The initial step was, however, to obtain a fine photograph of the normal solar spectrum, so that the wave-lengths of the lines up to O [wave-length 3440] might be determined with precision.

In the spring of 1873 I published a paper on the diffraction spectrum of the Sun, illustrated by a photograph embracing the region from wave-length 4350 near G to 3440 near O, and in the fall of the same year took photographs of the spectra of several non-metals, notably nitrogen, carbon, and oxygen. The experiments were interrupted, in the spring of 1874, by going to Washington to superintend the photographic preparations for the United States observations on the Transit of Venus.

Since that time my experiments have been divided into two parts, an astronomical portion occupying principally the summer season, and a laboratory portion during the rest of the year. The former consisted of photographs and observations on the spectra of the stars, planets, and Sun; the latter, of photographic work on the spectra of the elements, and particularly the non-metals, and has led to the discovery of oxygen in the Sun.

In 1876, Dr. Huggins published a note in the Proceedings of the Royal Society, accompanied by a wood-cut of the spectrum of Vega, with a comparison solar spectrum. Seven lines were observed in the spectrum of Vega. In the summer and autumn of 1876 I made several photographs of the spectra of Vega, *a* Aquilæ, and Venus, and sent a note concerning them to this Journal.

Since that time Dr. Huggins has pursued the subject actively, in spite of the London atmosphere, and has attained very fine results, which I had the pleasure of seeing at his observatory last spring. These he is preparing to publish shortly. In my observatory photographs have been taken of the spectrum of Vega, Arcturus, Capella, *a* Aquilæ, Jupiter, Mars, Venus, the Moon, etc. Recently the plan has been to have a comparison solar spectrum on every plate, derived either from the diffused light of our atmosphere, or from the Moon, or from Jupiter. In this way no difficulty in determining the wave-lengths of the lines is encountered, and the changes produced by our atmosphere are eliminated. The telescope and spectroscope are now in good working order, but to secure the requisite degree of precision of movement it has been necessary to make seven different driving-clocks before a satisfactory one was attained.

It has been remarked that, on account of the faintness of the light of stellar spectra, prolonged exposures of the sensitive plate are required. In former times, when the dry processes of photography were much less sensitive than the best wet plates, the exposure was limited by the length of time the plate could be left in the camera without being stained by drying. But now, since the gelatino-bromide process has been introduced, this obstacle has been removed, and a sensitive plate is sometimes exposed two hours to the spectrum of a star, and then almost an hour to Jupiter for the comparison spectrum. The best, and most sensitive, gelatine plates I have used are those made by Wratten & Wainwright of London. Dr. Huggins was good enough to call my attention to them.

It is not worth while to describe the various forms of spectroscope that have been employed in the last ten years: quartz Iceland spar, hollow prisms, and flint glass have been the materials, and they have been sometimes direct vision and sometimes on the usual angular plan. Gratings on glass and speculum metal given to me by Mr. Rutherfurd have been tried. The length of spectroscope has been sometimes twenty-eight feet and sometimes not as many inches.

The especial spectroscope for stellar work that is now on the telescope is intended to satisfy the following conditions: 1st, to get the greatest practicable dispersion with the least width of spectrum that will permit the lines to be seen; 2d, to use the entire beam of light collected by the 28-inch reflector or 12-inch achromatic without loss by diaphragms; 3d, to permit the slit to be easily seen, so that the star may be adjusted on it; 4th, to avoid flexure or other causes that might change the position of the spectrum on the sensitive plate in pointing the telescope first on one and then on another object; 5th, to admit of observing the spectrum on the sensitive plate at any time during an exposure without risk of shifting or disarrangement. The dispersion is produced by two heavy flint prisms, which are devoid of yellow color; the telescopes are about six inches in focal length, and the slit has a movable plate in front of it, enabling the operator to uncover either the upper or the lower portion at will.

During the past summer this spectroscope has been used with the Clark refractor of 12 inches aperture, partly because the 28-inch reflector has been kept unsilvered since it was used in taking photographs of the Transit of Mercury, on account of its employment in certain experiments on the Sun. Moreover, there is an advantage possessed by the refractor for this work which does not appear at first sight. Naturally one supposes that a reflector which brings all the rays from the star, no matter what their refrangibility, to a focus in one plane, would be best, because when the slit is put in that plane it is equally illuminated by rays of all refrangibilities, and the spectrum will be parallel-sided in its whole length. On the other hand, a refractor is not achromatic, for the violet end of the spectrum comes to a focus either inside or outside of the plane of the rays in the middle of the spectrum, and in observing the spectrum it is not parallel-sided. This peculiarity was used by Mr. Rutherfurd to enable him to correct a telescope lens for the ultra violet rays. It is easy, therefore, with a refractor so to adjust the position of the slit that you may have a spectrum tolerably wide at F and G, and which gradually diminishes in width toward H, and finally becomes almost linear at M. Now, as the effect of atmospheric absorption on the spectrum increases as you pass from G toward H and above H, by diminishing the width of the spectrum you can in some measure neutralize the effect, and at one exposure obtain a photograph of nearly uniform intensity from end to end, though it is of variable width. If it were not for this, it would be necessary to have the spectrum over-exposed at G in order to be visible above H, or else to resort to an elaborate diaphragming, which is difficult.

It is my intention next season to return to the use of the 28-inch reflector, because it collects nearly five times as much light as the 12-inch does, after making allowance for the secondary mirror. Of course, in a large reflector the difficulties of flexure and instability of the optical axis are much increased, and keeping a star on the slit will be troublesome, especially as the magnifying power on the image is about 50.

As to the results obtained, it has already been mentioned that the spectra of several stars and planets have been photographed. The subject of planetary spectra will be reserved for a future communication. A preliminary examination at once shows that these stellar spectra are divisible into two groups: first, those closely resembling the solar spectrum; and second, those in which there are relatively but few lines, and these of great breadth and intensity. The photographs of the spectra of Arcturus and Capella are so similar to the solar spectrum, that I have not up to the present detected any material differences. But, on the other hand, the spectra of Vega and α Aquilæ are totally different, and it is not easy without prolonged study and the assistance of laboratory experiments to interpret the results, and even then it will be necessary to speak with diffidence. I have not as yet obtained any stellar spectrum photographs belonging to the third and fourth groups of stellar spectra as described by Secchi. These, if obtainable, will aid materially in discussing the whole subject; but unless a star passes near the zenith it is hard to make a fair study of its spectrum by photography, because atmospheric absorption in the ultra violet region increases rapidly as the altitude decreases. In the case of the Sun, I have found that at sunset the exposure necessary to photograph the spectrum above H is often 200 times as long as at midday.

In the case of the spectrum of Vega when examined by the eye, the lines C, F, near G and *h*, are readily visible, but lines such as D and *b* are relatively faint. It is clear, then, that hydrogen exists to a large extent in the atmosphere of that star. But on examining the photograph of its spectrum it is evident that other lines just as conspicuous as the hydrogen lines are present. One of these corresponds in position and character to H_1, and seems to coincide with a calcium line. It appears to me, however, that the evidence of this coincidence is not complete.

In attempting to reason from these photographs, as the matter now stands, it is necessary to try at every step further experiments in order to find out whether the facts agree with hypothesis, and it is this very condition of affairs that gives hopes of results valuable in their bearing on terrestrial chemistry and physics. In the photographs of the spectrum of Vega there are eleven lines, only two of which are certainly accounted for; two more may be calcium; the remaining seven, though bearing a most suspicious resemblance to the hydrogen lines in their general characters, are as yet not identified. It would be worth while to subject hydrogen to a more intense incandescence than any yet attained, to see whether in photographs of its spectrum under those circumstances any trace of these lines, which extend to wavelength 3700, could be found.

It is to be hoped that before long we may be able to investigate photographically the spectra of the gaseous nebulæ, for in them the most elementary condition of matter and the simplest spectra are doubtless found.

[From the American Journal of Science, Vol. XXIII., May, 1882.]

Art. XXXV.— *On Photographs of the Spectrum of the Nebula in Orion.*[*] By Henry Draper, M. D.

[Read before the National Academy of Sciences, April, 1882, at Washington.]

For about eighteen months I have been giving attention to the Nebula in Orion with two objects in view: first, to ascertain whether any changes are taking place in that body, by making a series of photographs to be compared in the future with a similar series; and second, to photograph the spectrum of the nebula in various parts, so as to see whether any new lines could be found, and also whether the composition is uniform throughout.

As to the first of these objects, I have recently succeeded in taking a very fine and extensive photograph of the nebula containing most of the delicate outlying parts which were not in my earlier photographs. This is in the hands of the photolithographer now, and will shortly be published. The experiments have been very difficult, because an exposure of more than two hours in the telescope has been necessary, and an exceedingly minute motion of the stars relative to the sensitive plate will become apparent on account of the high magnifying power (180), employed.

In carrying out the second object two contrivances have been used: first, a direct vision prism in the cone of rays from the objective before they had reached a focus; and second, the two-prism spectroscope with which I have taken photographs of stellar spectra for some years past.

During the month of March I have made two good photographs with each of these arrangements. Those with the direct vision prism, without a slit, have of course demanded that the image should be kept stationary on the sensitive plate throughout the exposure, viz. two hours, and they are as difficult to get as good photographs of the nebula itself. On the contrary, those obtained with the slit spectroscope do not require the same steadfast attention.

The results derived from these photographs are interesting, partly from what they show and partly from what they promise in the future. A number of photographs, under various conditions, will be needed for the full elucidation of the subject.

The most striking feature is perhaps the discovery of two condensed portions of the nebula just preceding the trapezium, which give a continuous spectrum. At those places there is either gas under great pressure, or liquid, or solid. I have not been able to detect any stars of sufficient magnitude in these portions to produce this effect, either in my photographs of the nebula or in any of the well-known drawings of this object. It seems to me, also, that the photographs show evidence of continuous spectrum in other parts of the nebula. In these respects the conclusions arrived at by Lord Rosse in his memoir (Phil Trans. Royal Society, June 20, 1867, page 70) are to a certain extent borne out.

The hydrogen line near G, wave-length 4340, is strong and sharply defined; that at *h*, wave-length 4101, is more delicate, and there are faint traces of other lines in the violet. Among these lines there is one point of difference, especially well shown in a photograph where the slit was placed in a north and south direction across the trapezium; the $H\gamma$ line, λ 4340, is of the same length as the slit, and where it intersects the spectrum of the trapezium stars a duplication of effect is visible. If this is not due to flickering motion in the atmosphere, it would indicate that hydrogen gas was present even between the eye and the trapezium. I think the same is true of the $H\delta$ line, λ 4101. But in the case of two other faint lines in this vicinity I think the lines are not of the length of the slit, one being quite short and the other discontinuous. If this observation should be confirmed by future photographs of greater strength, it might point to a non-homogeneous constitution of the nebula, though differences of intrinsic brightness would require to be eliminated.

The April number of the American Journal of Science contains an account of a photograph of the spectrum of this nebula taken by Dr. Huggins. I have not found the line at λ 3730, of which he speaks, though I have other lines which he does not appear to have photographed. This may be due to the fact that he had placed his slit on a different region of the nebula, or to his employment of a reflector and Iceland spar prism, or to the use of a different sensitive preparation. Nevertheless, my reference spectrum extends beyond the region in question.

As illustrating the delicacy of working required in this research it may be mentioned that in one of these photographs the spectrum of a star of the tenth magnitude is easily discerned. It is only a short time since it was considered a feat to get the image of a ninth magnitude star, and now the light of a star of one magnitude less may be photographed even when dispersed into a spectrum.

Note on Photographs of the Spectrum of Comet b 1881.

By Henry Draper, M.D.

The appearance of a large comet has afforded an opportunity of adding to our knowledge of these bodies by applying to it a new means of research. Owing to the recent progress in photography, it was to be hoped that photographs of the comet and even of its spectrum might be obtained, and peculiarities invisible to the eye detected. For such experiments my observatory was prepared, because, for many years, its resources have been directed to the more delicate branches of celestial photography and spectroscopy, such as photography of stellar spectra and of the nebulæ. More than a hundred photographs of spectra of stars have been taken, and in the Nebula of Orion details equal in faintness to stars of the 14.7 magnitude have been photographed.

It was obvious that, if the comet could be photographed by less than an hour's exposure, there would be a chance of obtaining a photograph of the spectrum of the coma, especially as it was probable that its ultra-violet region consisted of but few lines. In examining my photographs of the spectrum of the voltaic arc, a strong band or group of lines was found above H; and on the hypothesis that the incandescent vapor of a carbon compound exists in comets, this band might be photographed in their spectrum.

Accordingly, at the first attempt a photograph of the nucleus and part of the envelopes was obtained in 17 minutes, on the night of June 24th, through breaks in the clouds. On succeeding occasions when an exposure of 162 minutes was given the tail impressed itself to an extent of nearly 10 degrees in length.

I next tried, by interposing a direct-vision prism between the sensitive plate and the object-glass, to secure a photograph which would show the continuous spectrum of the nucleus and the banded spectrum of the coma. After an exposure of 83 minutes, a strong picture of the spectrum of the nucleus, coma, and part of the tail was obtained, but the banded spectrum was overpowered by the continuous spectrum.

I then applied the two-prism spectroscope used for stellar spectrum photography, anticipating that, although the diminution of light would be serious after passing through the slit, two prisms, and two object-glasses, yet the advantage of being able to have a juxtaposed comparison spectrum would make the attempt desirable, and moreover, the continuous spectrum being more weakened than the banded by the increased dispersion, the latter would become more distinct.

Three photographs of the comet's spectrum have been taken with this arrangement, with exposures of 180 minutes, 196 minutes, and 228 minutes, and with a comparison spectrum on each. The continuous spectrum of the nucleus was plainly seen while the photography was in progress. It will take some time to reduce and discuss these photographs and prepare the auxiliary photographs which will be necessary for their interpretation. For the present, it suffices to say that the most striking feature is a heavy band above H which is divisible into lines, and in addition two faint bands, one between G and *h* and another between *h* and H. I was very careful to stop the exposure before dawn, fearing that the spectrum of daylight might become superposed on the cometary spectrum.

It would seem that these photographs strengthen the hypothesis of the presence of carbon in comets; but a series of comparisons will be necessary, and it is not improbable that a part of the spectrum may be due to other elements.

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